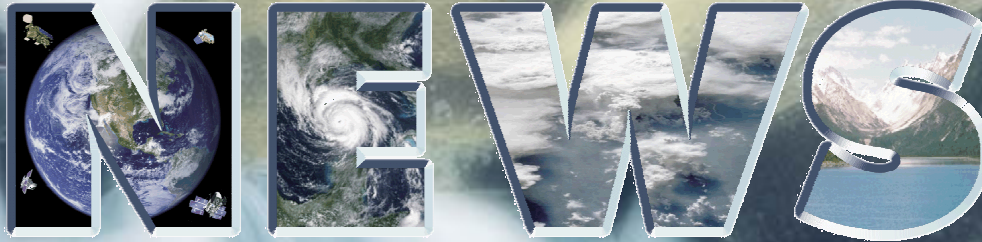# NASA ENERGY AND WATER CYCLE STUDY

NEWS

D. Belvedere (UMBC), P. Houser (GMU/CREW),
J. Entin (NASA-HQ), W. Rossow (GISS),
W. Lapenta (MSFC), B. Lin (LaRC),
E. Njoku (JPL), C. Schlosser (MIT),
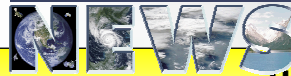R. Schiffer (UMBC)

Outline:
- Define water and energy cycle
- Why water & energy cycle?
- Outstanding issues
- NEWS Strategy & Plan
- Partnerships

NEWS Challenge:
Document and enable improved, observationally-based, predictions of water and energy cycle consequences of Earth system variability and change.
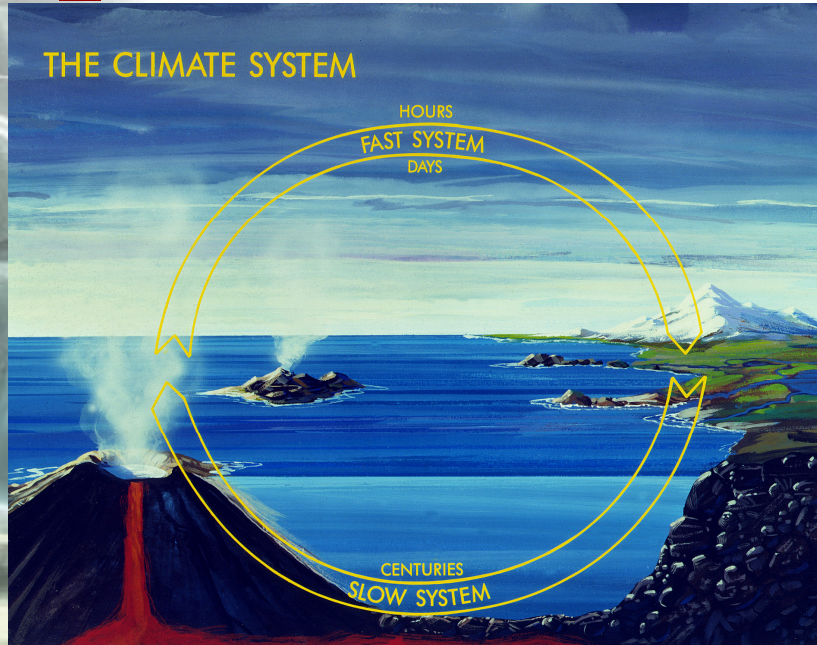
The global water and energy cycle encompasses the movements, transformations, and reservoirs of water, energy, and water-borne materials throughout the Earth system and their interactions with ecosystems and the global water system. The global water and energy cycle operates on the full continuum of space and time scales and involves phase changes and energy exchanges.

The Water and Energy Cycle

Water in the climate system functions on <u>all</u> time scales: From hours to centuries

THE CLIMATE SYSTEM
HOURS
FAST SYSTEM
DAYS
CENTURIES
SLOW SYSTEM

The Energy and Water Cycles are <u>*tightly intertwined*</u> – Solar radiation drives and feedbacks with the water cycle, and energy is transferred through water movement and phase change.

- *Water exists in all three phases in the climate system and the phase transitions are a significant factor in the regulation of the global and regional energy balances*
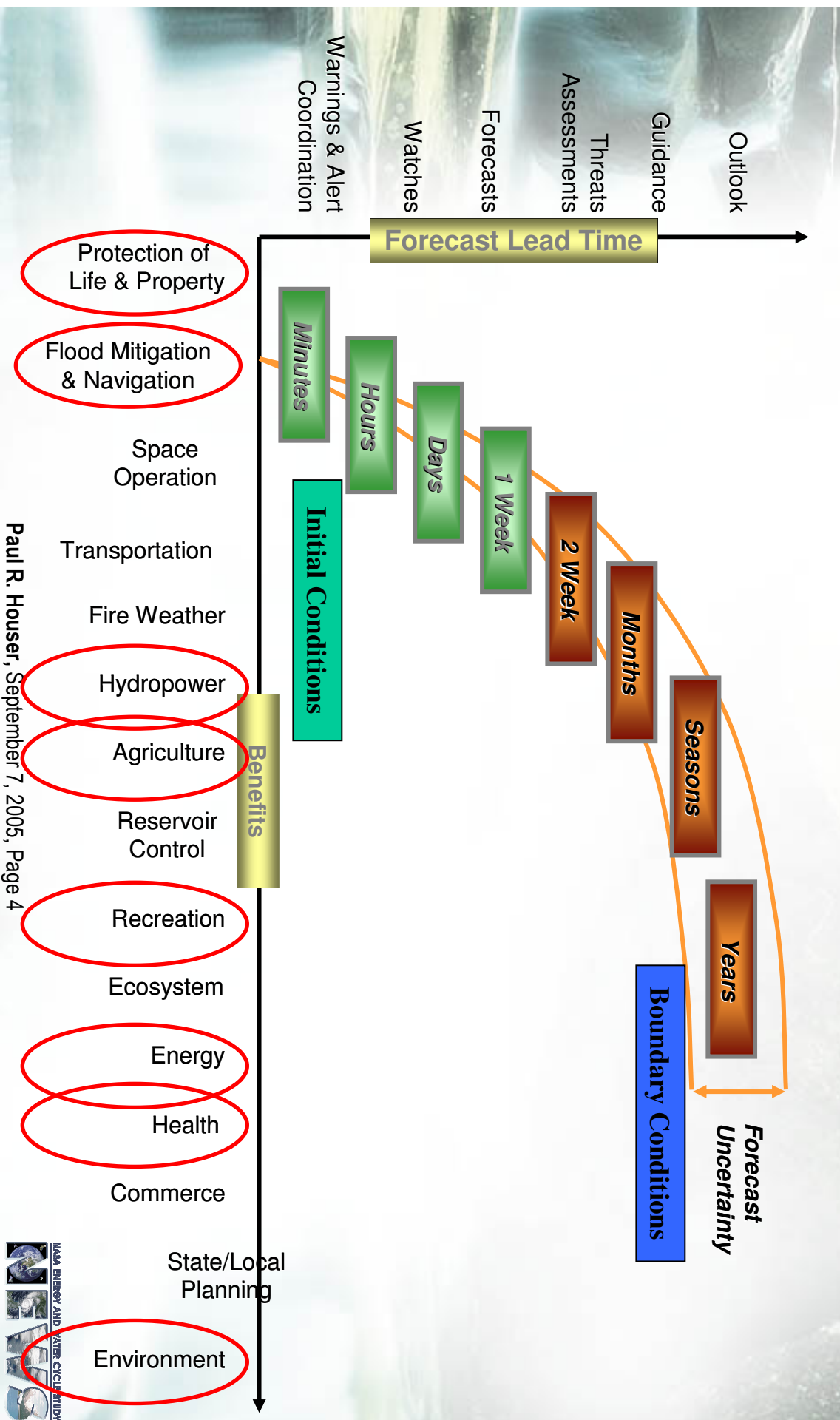
- *Water vapor in the atmosphere is the principal greenhouse gas and clouds at various levels and composition in the atmosphere represent both positive and negative feedback in climate system response*

- *Water is the ultimate solvent and global biogeochemical and element cycles are mediated by the dynamics of the water cycle*

- *Water is the element of the Earth system that most directly impacts and constraint human society and its well-being.*

NASA ENERGY AND WATER CYCLE STUDY
NEWS

Seamless Suite of Forecasts to meet W&E cycle needs

Forecast Lead Time

- Warnings & Alert Coordination
- Watches
- Forecasts
- Threats Assessments
- Guidance
- Outlook

Benefits

- Protection of Life & Property
- Flood Mitigation & Navigation
- Space Operation
- Transportation
- Fire Weather
- Hydropower
- Agriculture
- Reservoir Control
- Recreation
- Ecosystem
- Energy
- Health
- Commerce
- State/Local Planning
- Environment

Minutes
Hours
Days
1 Week
2 Week
Months
Seasons
Years

Initial Conditions

Boundary Conditions

Forecast Uncertainty

NASA ENERGY AND WATER CYCLE STUDY

Why study the water and energy cycle?...

Variations in greenhouse gases, aerosols, and solar activity force changes in climate…

…but, <u>consequences</u> of climate change are realized through the water cycle.

Thus, we must ***<u>characterize</u>***, ***<u>understand</u>***, and ***<u>predict</u>*** *variations in the global water cycle.*

Water and Energy is linked to all 12 Science Application Themes.

Carbon Management

Water Management

Agricultural Competitiveness

Public Health

Homeland Security

Invasive Species

Energy Forecasting

Coastal Management

Ecological Forecasting

Aviation Safety

Disaster Preparedness
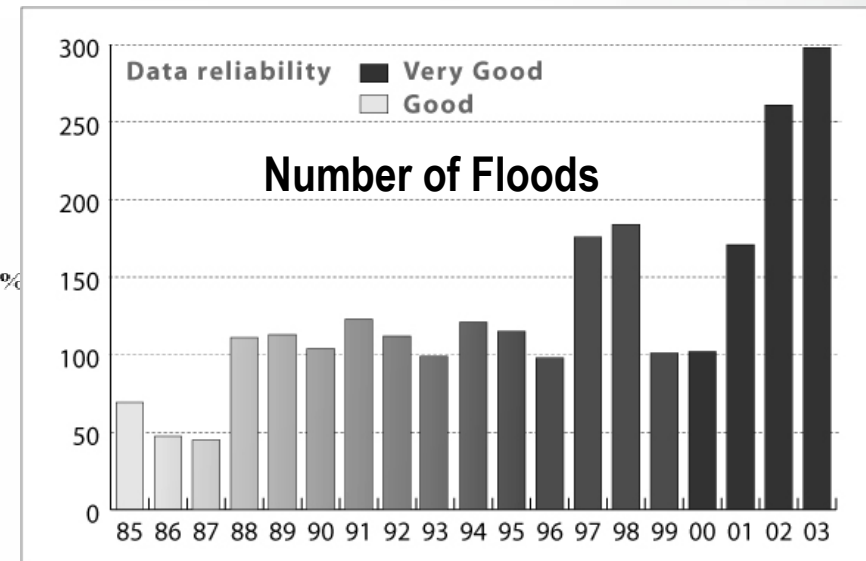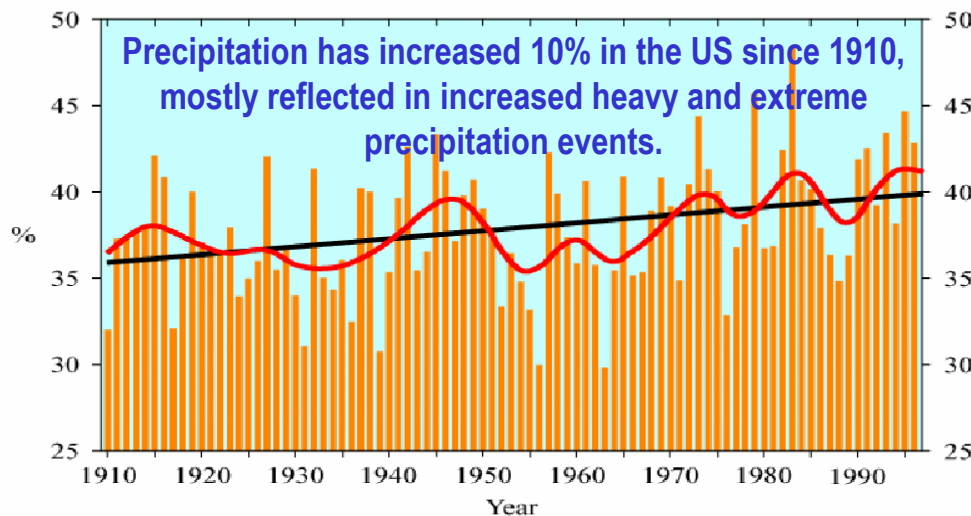
Air Quality

NASA ENERGY AND WATER CYCLE STUDY NEWS

A generally accepted hypothesis regarding global water cycle changes:

"According to model predictions, the *most significant manifestation of climate change would be an acceleration of the global water cycle, leading to … a general exacerbation of extreme hydrologic regimes, floods and droughts*" (NASA-GWEC, 2000).

"*There is evidence that suggests that the global hydrologic cycle may be intensifying, leading to an increase in the frequency of extremes*" (USGCRP water cycle science plan)

Climate models generally project an acceleration in the rate of global water cycling and an increase in global precipitation … (Morel, GEWEX News, 2001)
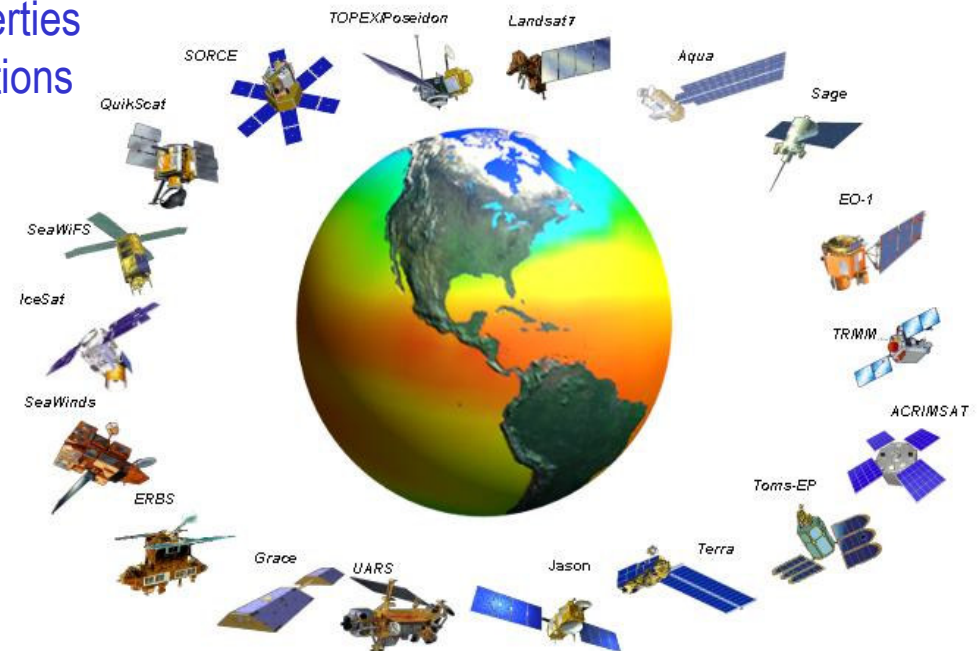

Precipitation has increased 10% in the US since 1910, mostly reflected in increased heavy and extreme precipitation events.

Number of Floods

From Dartmouth

What we know

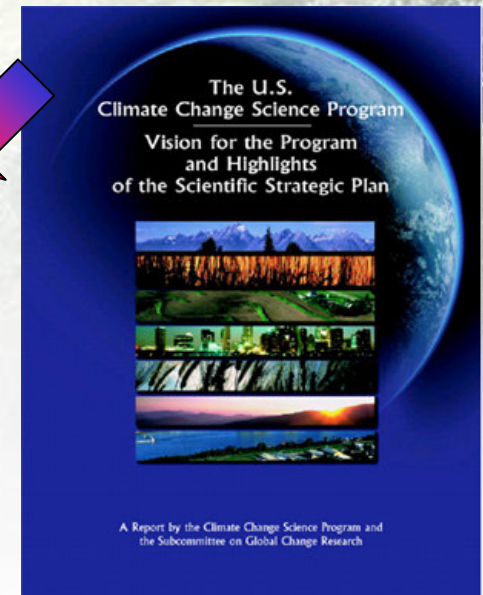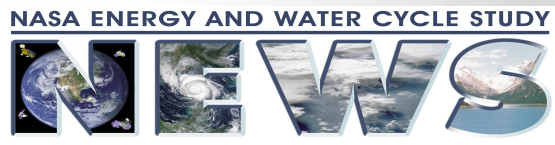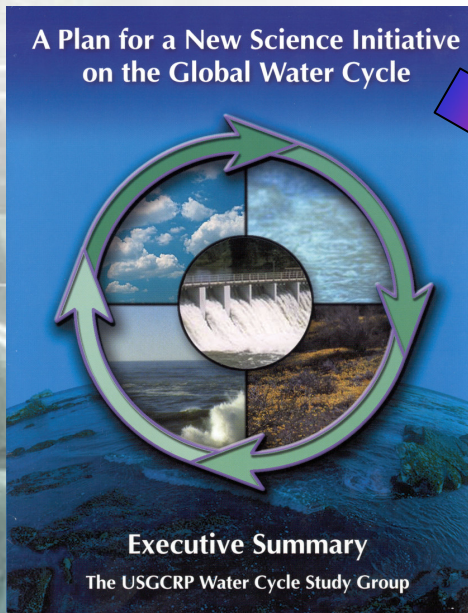- global atmospheric and surface temperature distributions
- top-of-the-atmosphere radiation fluxes
- point processes

What we need to know

- global precipitation and water vapor distributions
- cloud radiation absorption and scattering properties
- global soil moisture, snow cover/depth distributions
- surface runoff
- evaporation
- land surface/atmosphere feedbacks
- uncertainties in integrated E&WC processes

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A Plan for a New Science Initiative on the Global Water Cycle

Executive Summary
The USGCRP Water Cycle Study Group

The U.S. Climate Change Science Program
Vision for the Program and Highlights of the Scientific Strategic Plan

A Report by the Climate Change Science Program and the Subcommittee on Global Change Research

What are the causes of water cycle variations?

Are variations in the global and regional water cycle predictable?

How are water and nutrient cycles linked?

NASA Earth Science Program Water & Energy Cycle Science Questions (7 of 24 questions):

How are global precipitation, evaporation and the cycling of water changing?

What are the effects of clouds and surface hydrologic processes on Earth's climate?

How are variations in local weather, precipitation and water resources related to climate variation?

What are the consequences of climate change and increased human activities for coastal regions?

How can weather forecast duration and reliability be improved?

How can predictions of climate variability and change be improved?
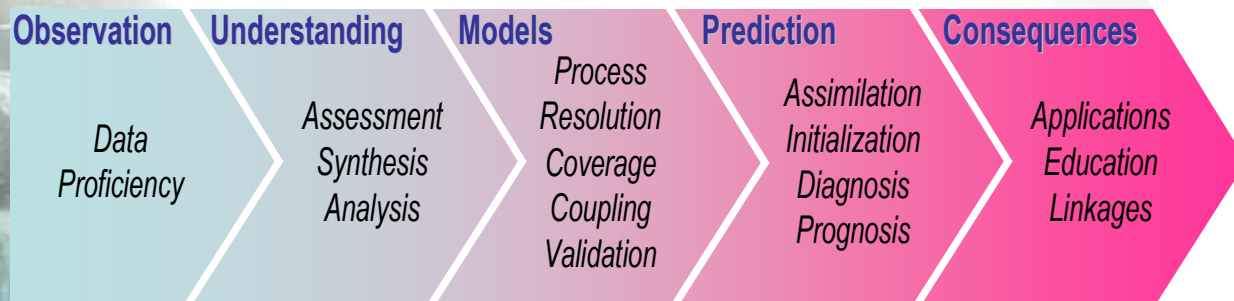
How will water cycle dynamics change in the future?

NASA Water and Energy cycle Study (NEWS) Challenge:

Document and enable improved, observationally-based, predictions of water and energy cycle consequences of Earth system variability and change.

NEWS Integrated Water and Energy Cycle Research

From Observations to Consequences

The NEWS challenge is **global** in scale and requires the integration of NASA **system components** to **make decisive progress toward the NEWS challenge** in an **end-to-end program**

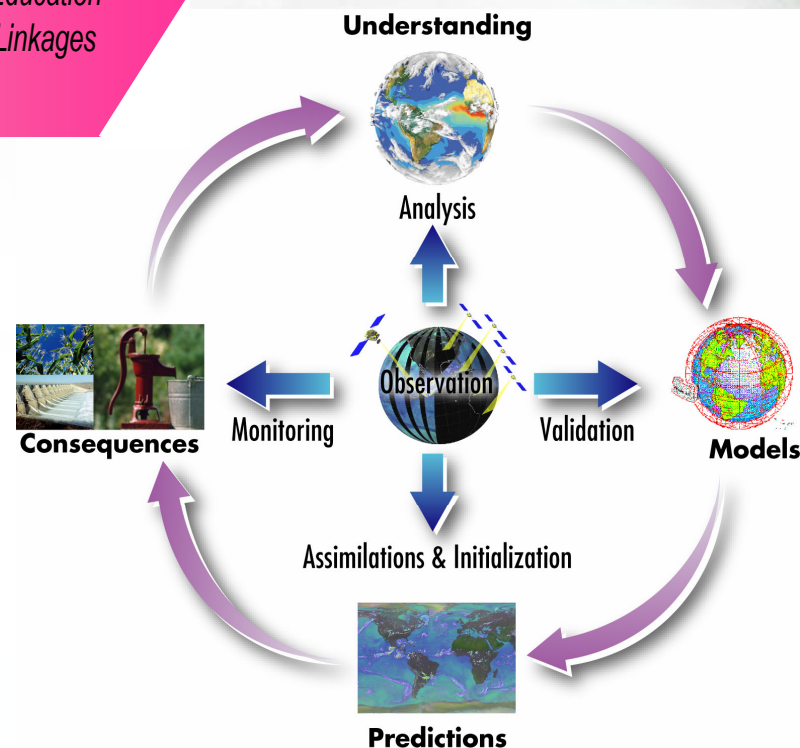| Observation	Understanding	Models	Prediction	Consequences
Data Proficiency	Assessment Synthesis Analysis	Process Resolution Coverage Coupling Validation	Assimilation Initialization Diagnosis Prognosis	Applications Education Linkages

Product-driven NEWS investigations directly cooperate with NASA to produce a coordinated cross-discipline comprehensive solution.

Discovery-driven NEWS investigations carried out by individuals or small groups of scientists to make advances in our understanding of key Earth-science processes.

NEWS is a interdisciplinary program: Discipline-based research will be performed by existing NASA disciplinary programs.

NEWS Science Integration Team: Support NEWS investigations and integrate their research results to address NASA-ESE science questions. The NEWS integration group will work with NEWS investigations to implement their results into a larger coordinated product, such as a NASA model, data system, etc.

Understanding — Analysis
Models — Validation
Predictions — Assimilations & Initialization
Consequences — Monitoring
Observation

NASA ENERGY AND WATER CYCLE STUDY
NEWS

NASA Energy and Water cycle Study Road Map
DRAFT Unofficial Version (4.22.2004)

Knowledge Base

NASA ENERGY AND WATER CYCLE STUDY — NEWS

Focus Area Linkages
- **C** = Carbon
- **V** = Climate variability
- **A** = Atmospheric composition
- **W** = Weather
- **S** = Surface & interior

- **T** = Technology development
- ✈ = Field campaign
- ▢ = Funded
- ▢ = Unfunded

NEWS Challenge:
Document and enable improved, observationally-based, predictions of water and energy cycle consequences of Earth system variability and change.

Address the ESE vision; deliver and evaluate system

Phase 3 Deliverables:
- **Dataset gaps filled and extended**
- **Intensive prediction system testing**
- **Prediction system delivery**

APPLICATION:
- **Improved water & energy cycle forecasts for use in decision support systems**

Predict consequences of climate change
Global hydrologic warning system **T**
Demonstrate useful predictions **T W V**

ANALYSIS & PREDICTION:
- **Understand variability in stores and fluxes**
- **Accurate cloud prediction**
- **Improve latent heating & convection models**

Reprocess combined observation record **V**
Demonstrate prediction capacity **W V**
Full end-to-end system test **T**

Address deficiencies and build prediction system

Phase 2 Deliverables:
- **Fix model problems with new observations**
- **New measurement approaches developed**
- **End-to-end prediction system developed**

Observations used in planning
Test prediction of extremes **W V**
Develop application metrics

Enhanced RT models **T V W** ✈
Improved physics **C V W** ✈ Model convergence
Super-parameterization **T W V**
Multi-platform analysis **T**

Advanced multi-platform retrievals **T** ✈
Experimental W&E observation system **T** ✈
First Coordinated W&E Obs W V C Cold seasons ✈
GPM AQUARIUS HYDROS **T** Surface water **T** ✈

Comprehensive W&E cycle data management and retrieval system **T** ✈

Coordinated W & E system **T**

OBSERVATION:
- **Quantify mean state, variability, and extremes of the water & energy cycles**
- **Flux, transport, and storage rate quantification**

Exploiting current capabilities and preparing for the future

Phase 1 Deliverables:
- **First coordinated global W&E description**
- **Current prediction system evaluation**
- **Identify required system improvements**

Application
Selected demonstrations
Climatology baselines **V**
Establish requirements **T**

Prediction
Land-cloud model **C V A W** ✈
Multi-platform analysis **T** Physics-based modeling **T**
New climate datasets **V** OSSEs ✈

Observation
Advanced Analysis **T**
TRMM TERRA AQUA GRACE ICESAT **S C W A V**
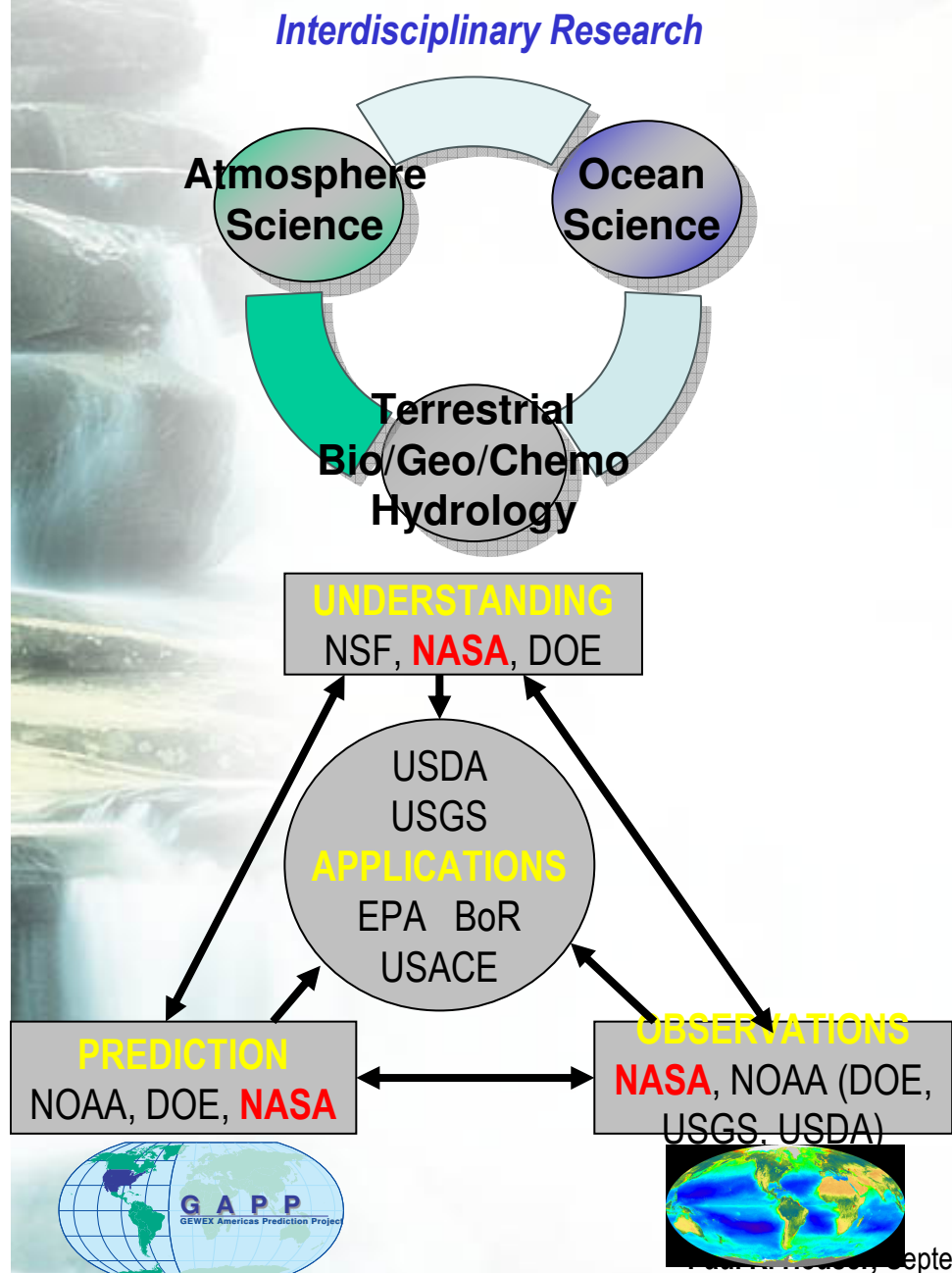AURA CloudSAT CALIPSO **V A W**

NEWS Components

NEWS Constraints

- Focus on water and energy processes and dynamics in the climate system.
- The NEWS challenge is a **global scale** objective
- Integrate water and energy cycle system components (observations and predictions)
- NEWS elements: **Observation, Understanding, Models, Prediction and Consequences**
- Make **decisive progress** toward NEWS challenge
- NASA administers the water and energy cycle focus area as an **end-to-end program**
- DSS development is not supported by NEWS

NEWS Objectives:

- Develop and deploy experimental **E&WC global observing system**
- **Document the global E&WC** by obtaining complete observational record of all associated relevant geophysical properties
- Build **fully interactive global climate model** that encompasses process-level E&WC forcings and feedbacks – *Climate models that can predict weather-scale extremes*
- Create global surface and atmosphere **data assimilation system for E&WC variables**
- **Assess variability of the global E&WC** on time scales ranging from seasonal to decadal, and space scales ranging from regional to continental to global
- Support the **application of climate prediction capabilities** for estimating the impact of climate variability and change on water resources

NEWS Linkages

Interdisciplinary Research

Atmosphere Science

Ocean Science

Terrestrial Bio/Geo/Chemo Hydrology

UNDERSTANDING
NSF, **NASA**, DOE

USDA
USGS
APPLICATIONS
EPA   BoR
USACE

PREDICTION
NOAA, DOE, **NASA**

OBSERVATIONS
NASA, NOAA (DOE, USGS. USDA)

- Formal – CCSP
  - Water Cycle sub-group
    - Basic research (NSF, NOAA, DOE)
    - Applied research (EPA, BoR, USDA, USGS)
  - Climate Variability and Change group
  - Others (Atm. Comp., International, Human Dimensions, e
- Informal
  - NCAR - explicit water cycle program
  - GFDL
  - GAPP – small scale end to end / focused on prediction
  - CUASHI – land observation inspired research
- World Climate Research Program (WCRP)
  - Global Energy and Water Experiment (GEWEX)
  - Climate Variability (CLIVAR)
  - Climate and Cryosphere (CLIC)
- IGOS-Partners Water Cycle Theme
- Global Observing system (GCOS)
- Global Earth Observation (GEO and IWGEO)
- International Geosphere-Biosphere Programme (IGBP)
- Hydrology for Environment, Life, and Policy (HELP)
- Global Water System Project (GWSP)
- And many more….!

G A P P
GEWEX Americas Prediction Project

NASA ENERGY AND WATER CYCLE STUDY
NEWS
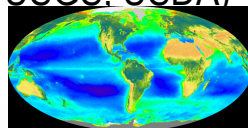
NEWS Observation

We must define a integrated water & energy observation system that can not only detect **global mean trends** but also **local variation of extremes**

Input - Output = Storage Change

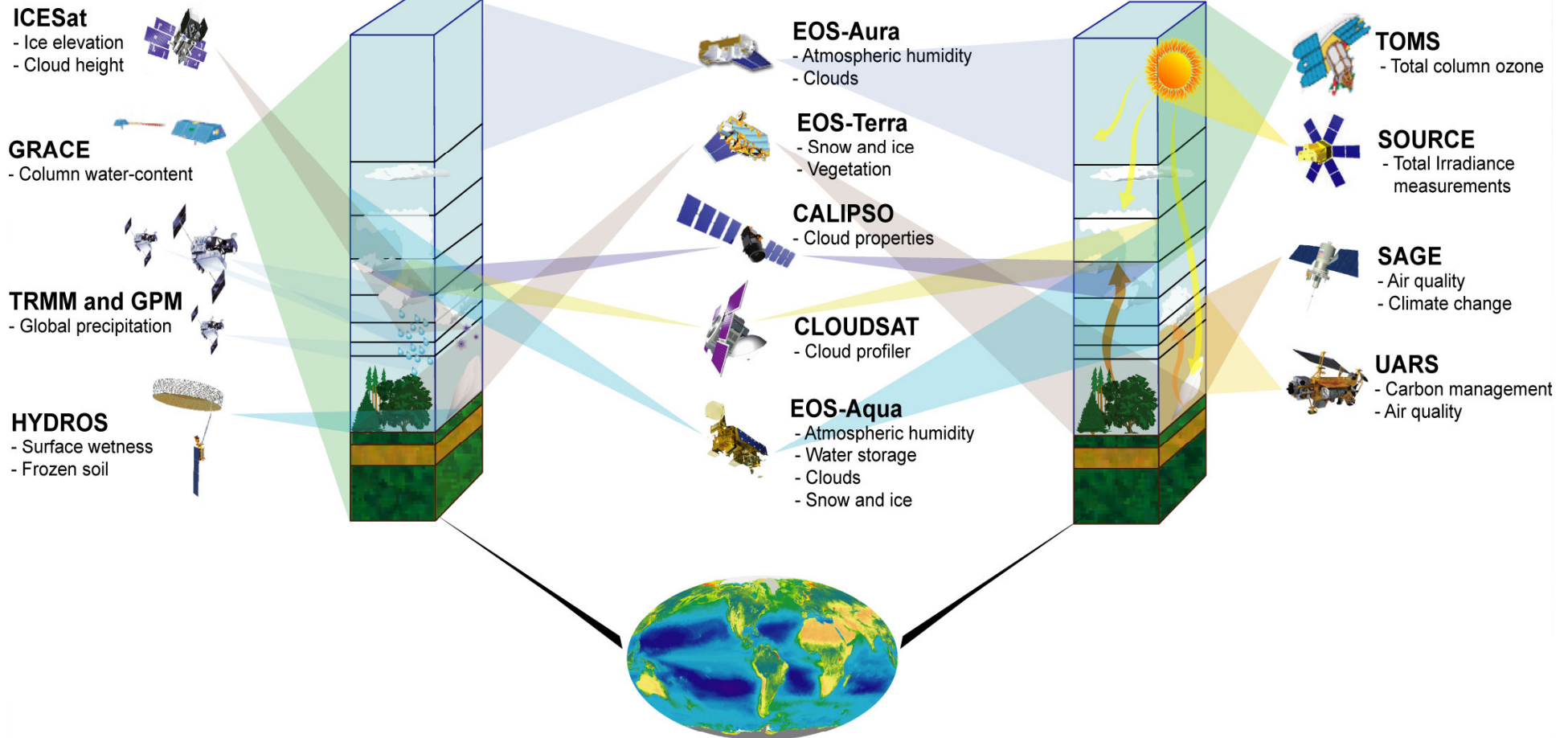**Transport + Evaporation - Precipitation – Runoff - P = ΔLand Storage + ΔWater Vapor**

L

$Q_a\, In$ S_a $Q_a\, Out$

E P_m P_a

Q_r

NASA ENERGY AND WATER CYCLE STUDY
NEWS

Water Cycle Missions

Water and Energy Cycle Missions

Energy Cycle Missions

ICESat
- Ice elevation
- Cloud height

GRACE
- Column water-content

TRMM and GPM
- Global precipitation

HYDROS
- Surface wetness
- Frozen soil

EOS-Aura
- Atmospheric humidity
- Clouds

EOS-Terra
- Snow and ice
- Vegetation

CALIPSO
- Cloud properties

CLOUDSAT
- Cloud profiler

EOS-Aqua
- Atmospheric humidity
- Water storage
- Clouds
- Snow and ice

TOMS
- Total column ozone

SOURCE
- Total Irradiance measurements

SAGE
- Air quality
- Climate change

UARS
- Carbon management
- Air quality

Complementary Water and Energy Cycle Missions

QuickSCAT
- Sea-surface wind velocity

EO-1 Landsat and NMP EO-1
- Land cover

NPOESS
- Global environmental conditions
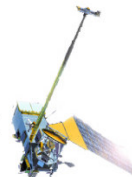
GOES
- Weather

Aquarius
- Global sea surface salinity
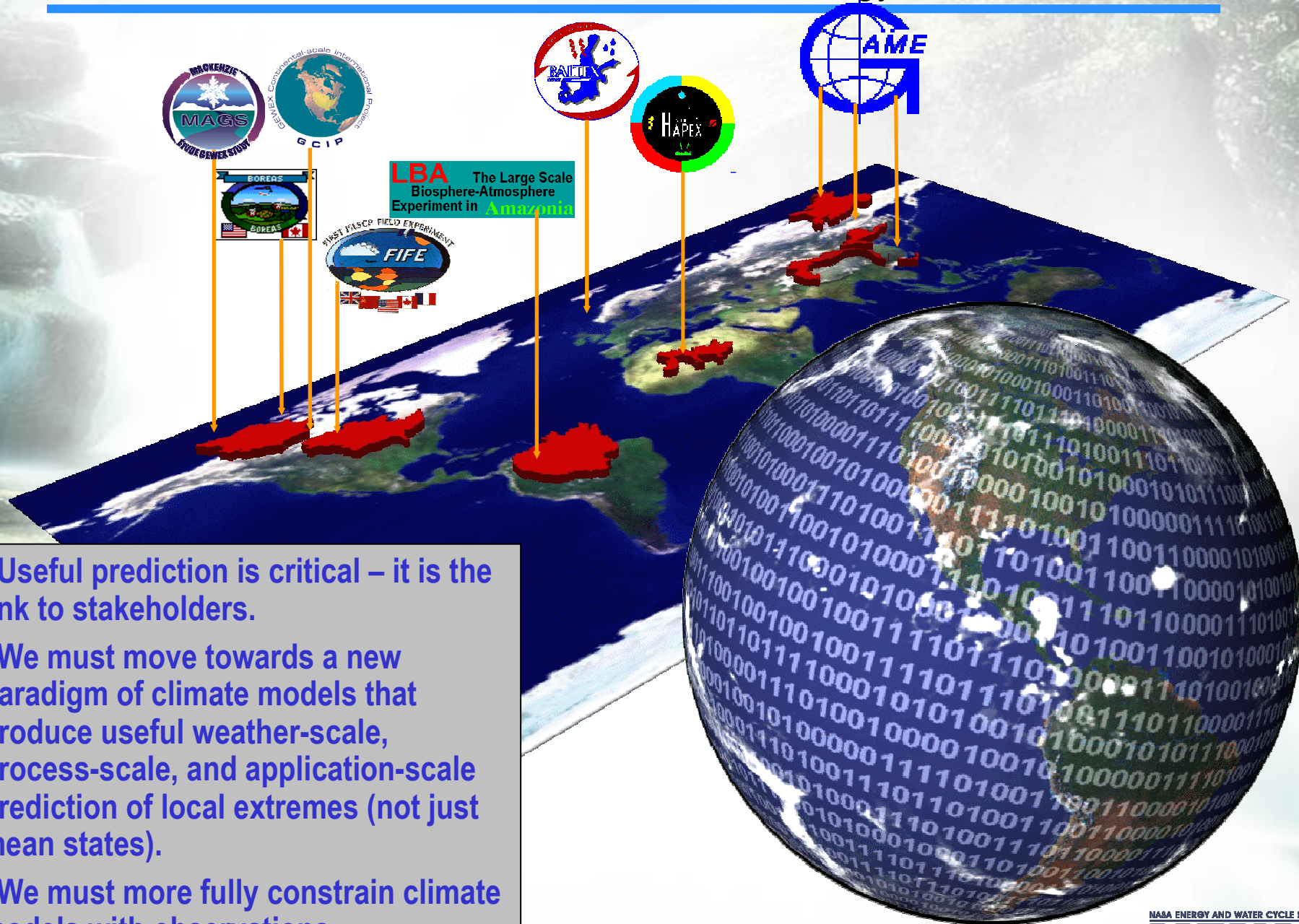
- **Useful prediction is critical – it is the link to stakeholders.**
- **We must move towards a new paradigm of climate models that produce useful weather-scale, process-scale, and application-scale prediction of local extremes (not just mean states).**
- **We must more fully constrain climate models with observations.**

Water & Energy Cycle Prediction Strategy

Global Warming Scenarios

Operational Climate Models (GFDL, NCAR, NCEP)

Integrated Water-Cycle Observation System: *Ground- and Space-Based Observing Programs*

- Advance Understanding and Model Physics
- Improve Initialization & Assimilation
- Diagnose and Identify Predictable Changes

Next-generation Global Water & Energy Cycle Prediction System

Water & Energy Cycle Prediction

What is science/model/data integration (coordinate, synthesis, enhance, link, interface, etc)?

- **Quantification:** Intercomparison, geolocation, balance assessment, error assessment, validation, super-ensembles, predictability assessment

- **Unification:** Data assimilation, calibration, time/space continuity, etc.

- **Collaboration:** Encouraging groups to team towards grand-challenge solutions.

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NEWS

Global Water & Energy Cycle: Advance Understanding and Model Physics

Climate models' grid-box representation of Earth's processes...
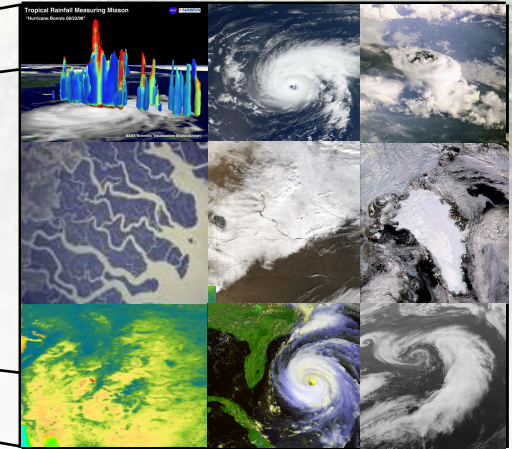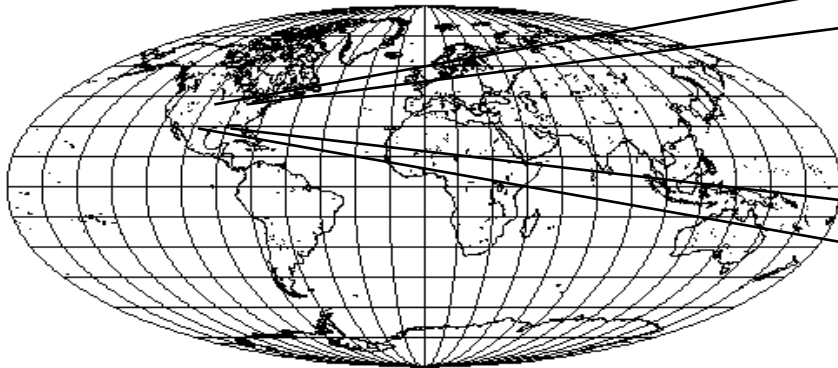
Each grid-box can only represent the "average" conditions of its area.

However, controlling processes of the water cycle (e.g. precipitation) vary over much smaller areas.

How can climate models effectively represent the controlling processes of the global water cycle?

"Conventional" approach: make the model grid-boxes smaller (increase resolution)

- **Slow progress: may take ~50 years to be computationally feasible**

Breakthrough approach: *Simulate a sample* of the small-scale physics and dynamics using high resolution *process-resolving models* within each climate model grid-box

- **"Short-cut" the conventional approach (~10 years to implement)**

NASA ENERGY AND WATER CYCLE STUDY
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End-to-end coordination enabling understanding and prediction of the Earth system:
Research driven by the needs of society
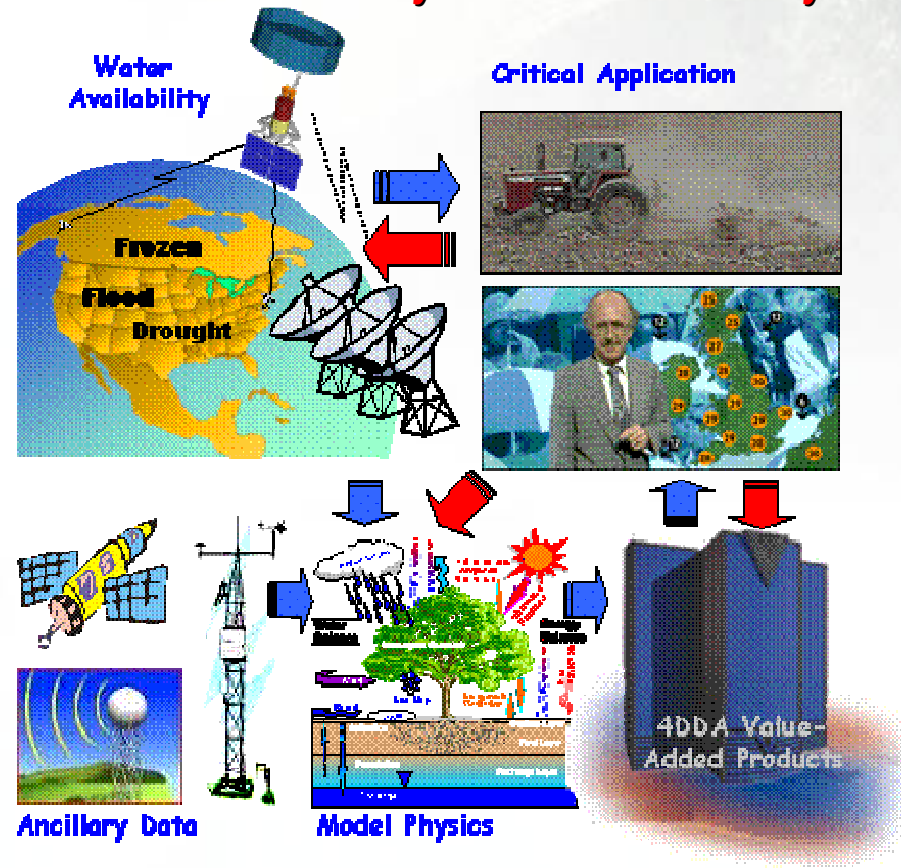
To deliver social, economic and environmental benefit to stakeholders through sustainable and appropriate use of water by directing towards improved integrated water system management

NEWS Science and Integration Team (NSIT)

NEWS Science Integration Team: Support NEWS investigations and integrate their research results to address NASA-ESE science questions. The NEWS integration group will work with NEWS investigations to implement their results into a larger coordinated product, such as a NASA model, data system, etc.

-Established by the Associate Administrator for Earth Science
-Will address all elements of WEC research and technology requirements and mission development.
-Provides a liaison with the other NASA Earth Science research focus areas.
-Serves as an interface to NASA system components.
-Focuses, coordinates and integrates the results of the NEWS investigations.

Current Members:
Bing Lin, Bill Rossow, Adam Schlosser, Bob Schiffer, Bill Lapenta, Eni Njoku, Paul Houser

NSIT Activities:
(1) **NEWS science integration:** Data product integration, PI coordination, Linkages to NASA system components, Interdiciplinary science
(2) **NEWS science gap filling:** Doing science that must be done, but was not proposed and/or funded
(3) **NEWS administration:** Organize meetings, NEWS planning & vision, POC responsibilities, Implementation plan updates, Representing NEWS to national and international partners

What is integration?
• Integrating observations to establish a more complete system description
• Integrating model components to build a earth modeling system
• Integrating research results to establish end-user solutions

Data Integration: Spatial and temporal rectification to allow intercomparison and quality evaluation of disparate model and observation data;
Data-Model Integration: Physical rectification or constraint of data and its error using four dimensional data assimilation and modeling techniques.
Model Integration: Using component models to build a system model.
Solution Integration: Integrating components (research results) to develop solutions
Interpersonal Integration: Interconnection of disparate water cycle research teams.

Science Integration (NSIT model):
• Data integration
• Coordinate energy and water process modeling
• Water & energy cycle trend and variability assessments
• End-user decision support & solution network connections

NASA ENERGY AND WATER CYCLE STUDY

NEWS Shared Services & NDIC ideas/feedback

NEWS Shared Services
- Share certain services to both increase efficiency, and encourage integrative activities

NEWS Data Integration Center: compile, integrate, diagnose and disseminate WEC observations and predictions that are required to pursue the NEWS challenge.
- Coordinate NEWS projects to form a unified virtual-space NEWS data center, to establish the NEWS products in consistent formats and common data processing frameworks.
- Acquire WEC observations and model predictions from all sources, for longest available period.
- Provide "one stop", streamlined access to coordinated and geolocated WEC data.
- Create a environment to attract scientists, end users, and educators to work with NEWS data.
- Provide a science and information link to other major global cycles, and disciplines.

**The NSIT has identified the need for the NDIC, and perceives its primary value to be:**
- Improved efficiency of centralized data storage.
- Value in having a common data framework.
- Value in providing provisional analysis tools.
- Providing standardized mode of interpolation (simple form in one place)

-> Recommendations, concerns, ideas? Other shared services?

Solution Networks

"A Water Cycle Solutions Network" was approved by NASA on June 3, 2005, to establish pathways and partnerships between NASA's water cycle research investments and decision support needs.

1. *Evolve a network of partners:* identify and analyze partner organizations to define collaboration pathways.
2. *Routinely identify, prioritize, mine and communicate relevant research products and results.*
3. *Optimize water cycle partner access* to research results and products to create a self-sustaining network.
4. *Analyze and document* the network effectiveness through metrics, resource estimates and documentation.
5. *Education and outreach* is important to help society understand and use the research in every-day application.
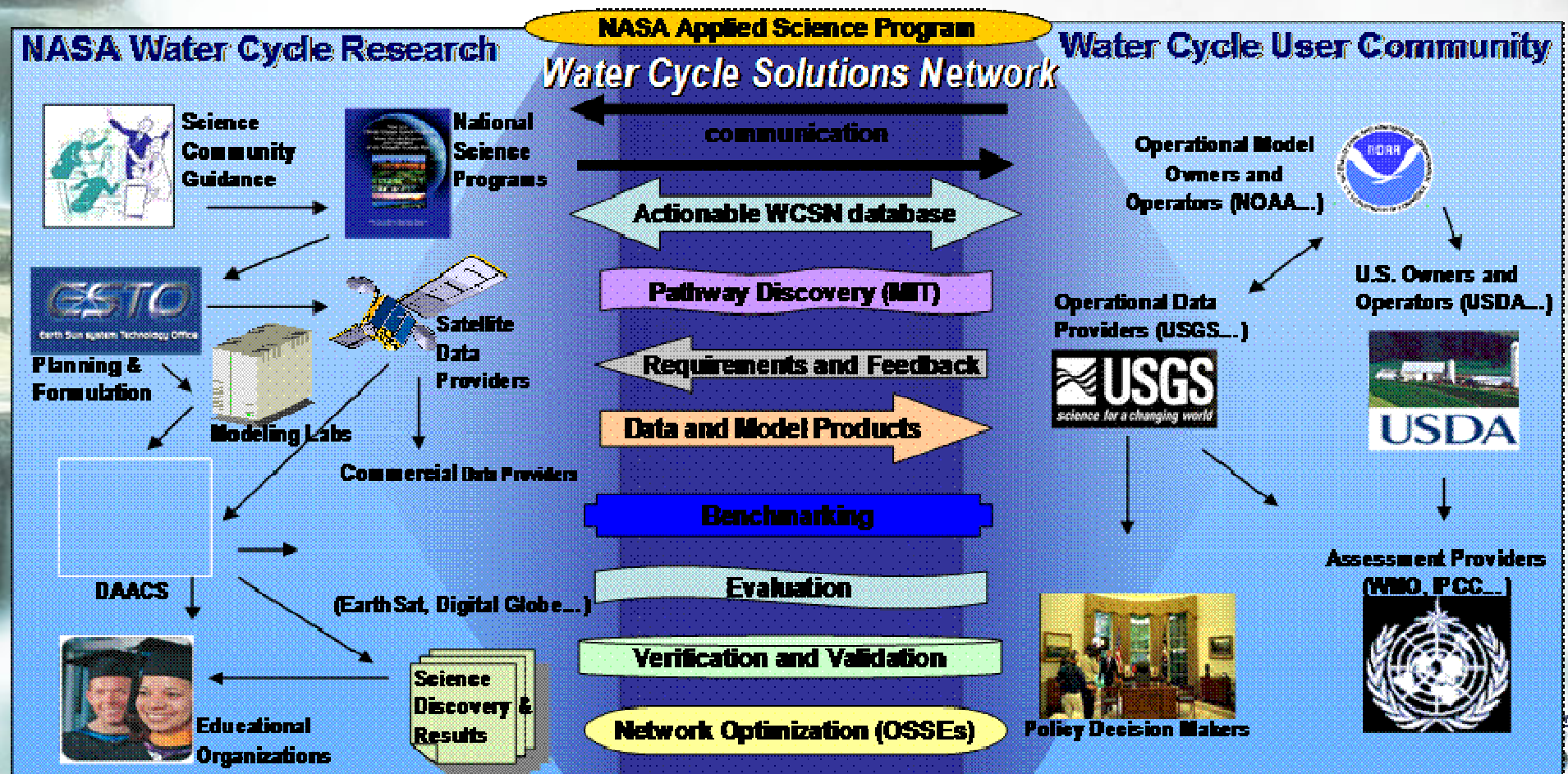
- Preparation:
  - Draft NEWS Implementation Plan
  - PI abstracts
  - GEWEX-NEWS Article
  - NEWS GAPS "POC Spreadsheet"

- Goals for meeting:
  - Identify and establish teaming and collaboration actions
  - Identify gaps and opportunities
  - Refine shared services ideas
  - Identify and understand important partnerships
  - Develop a plan to revise the IP and prepare it for external review by Jan 1, 2006

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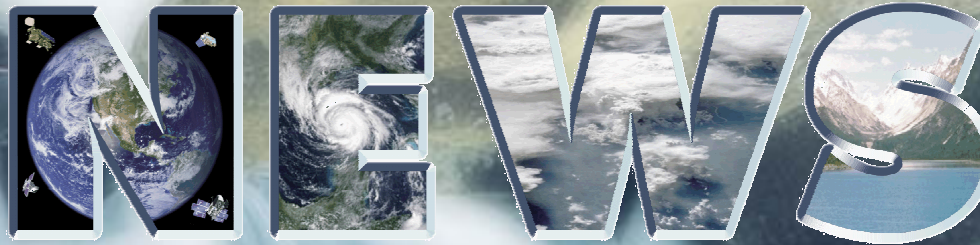
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NEWS Challenge:
Document and enable improved, observationally-based, predictions of water and energy cycle consequences of Earth system variability and change.

Status:

- Draft Implementation Plan: **http://wec.gsfc.nasa.gov**
- NSIT: 7-member NEWS science integration team formed
- Kick off meeting: Sept 7-9, 2005 New York (GISS)
- ROSES: Gap-filling amendment released

- IP Review: Spring 2006
- Public NEWS Meeting: Spring 2006